Remote Identification of Seafloor Properties in Denied Areas

Larry Mayer, Luciano Fonseca, Barbara Kraft, and Thomas Weber
Center for Coastal and Ocean Mapping
University of New Hampshire
Durham, NH 03824
phone: (603) 862-2615   fax: (603) 862-0839   email: lmayer@cisunix.unh.edu

Co-P.I.: Art Trembanis
Coastal Sediments Hydrodynamics and Engineering Lab
Department of Geological Sciences
University of Delaware
109 Penny Hall
Newark, DE 19711
phone: (302) 831-2498   email: art@udel.edu

LONG-TERM GOAL

The long-term goal of this project is to develop techniques to collect and use remotely sensed acoustic data to make robust predictions of seafloor physical, acoustic and geotechnical properties in denied areas at spatial and temporal scales appropriate for tactical applications. The work described is a collaboration of research groups at the University of New Hampshire (CCOM) and the University of Delaware (CSHEL). The project aims to take advantage of the recent results of theoretical and empirical studies in concert with new developments in sonar and Autonomous Underwater Vehicles (AUVs), to address the fundamental goal of remote characterization of seafloor properties in denied areas.

OBJECTIVES

1- Continue the development a physics-based model (ARA) for the prediction of seafloor properties from remotely collected acoustic backscatter data.

2- Test, validate, and update the model through the collection of carefully controlled ground-truth samples. In doing this we will also be adding to a growing database of physical and acoustic property measurements and inter-relationships.

3- Evaluate the feasibility of applying remote characterization algorithms to data collected with a small, low-powered multibeam sonar deployed from an autonomous underwater vehicle.

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APPROACH

Our initial approach involves four inter-related tasks: model development; ground-truth studies; multibeam evaluation, and; AUV integration. In year one, some of these tasks are being pursued independently; the results of the independent efforts will be brought together in year two.

Remote seafloor characterization using the ARA model:
With the development of multibeam echo-sounders the ability to look at the angular dependence of the acoustic response of the seafloor has opened up many new possibilities with respect to seafloor characterization. The angular response of the echo holds important information about seafloor roughness and volume reverberation, as well as acoustic impedance. Over the past few years, researchers at the University of New Hampshire have been developing a sophisticated sonar backscatter mosaicking tool (Geocoder – Fonseca and Calder, 2005) which includes a physics-based model known as ARA (Angular Response Analysis) that uses the angular dependence of backscatter for the remote prediction of seafloor properties. The ARA technique corrects multibeam sonar backscatter for radiometric and geometric factors, parameterizes the corrected angular response curve, and then applies a constrained (based on known physical property relationships) inversion (either a modified Jackson/Williams model or a Biot model) to solve for seafloor type (Fonseca et al., 2005).

Acoustic backscatter is normally modeled as a complex function of many sediment acoustic and physical properties, but the three main parameters that control the model are the acoustic impedance, the seafloor roughness, and the sediment volume heterogeneities. As a result, the backscatter strength measured by multibeam sonars is not only controlled by the acoustic impedance contrast between the water and the sediment (which is the key for seafloor characterization) but also responds to the seafloor roughness and to the sediment volume heterogeneities. This ambiguity between roughness, impedance, and volume heterogeneities is the main difficulty in the direct determination of seafloor properties based on remotely acquired backscatter. ARA attempts to address this problem by separating the portions of the acoustic backscatter return (returns from soundings near nadir are separated from returns from the outer beams) and in so doing, separate the contribution due to impedance contrast, roughness, and volume scatter. This separation is done through the calculation of a series of parameters that describe segments of the angular response curve including the slope and the intercept of the angular response curve (very similar to the Angle vs Offset – AVO – parameters used in multichannel seismic processing – Fig. 1). In general, the slope has a good correlation with the seafloor roughness, while the intercept has, in general, a good correlation with the impedance, although the actual relationship is complex and is described by the mathematical model for the acoustic backscatter.

Figure 1. AVO parameters

In our attempts to invert the backscatter model, it became clear that a direct inversion was an ill-posed problem. In order to overcome this limitation, we applied a "constrained interactive inversion of the model", imposing constraints based on Hamilton's database for sediment physical properties (Hamilton, 1974), and building parametric equations with the curve-description parameters calculated from the backscatter angular response. In this approach we do not allow the input parameters of the model to vary completely independently. Rather, the parameters are constrained by known physical property inter-relationships. In other words, the constrained inversion will increase the sound speed as the grain size increases, or decrease the porosity as the density increases as per the predictions of Hamilton's regression equations. Based on the calculated curve description parameters and the constrained interactive inversion of the acoustic backscatter model, it is possible to estimate the acoustic impedance, the seafloor roughness, volume backscatter, and other properties, including grain size of the insonified area on the seafloor. The model has been packaged in an interactive software tool that allows the rapid determination of the seafloor properties (Fig 2.).
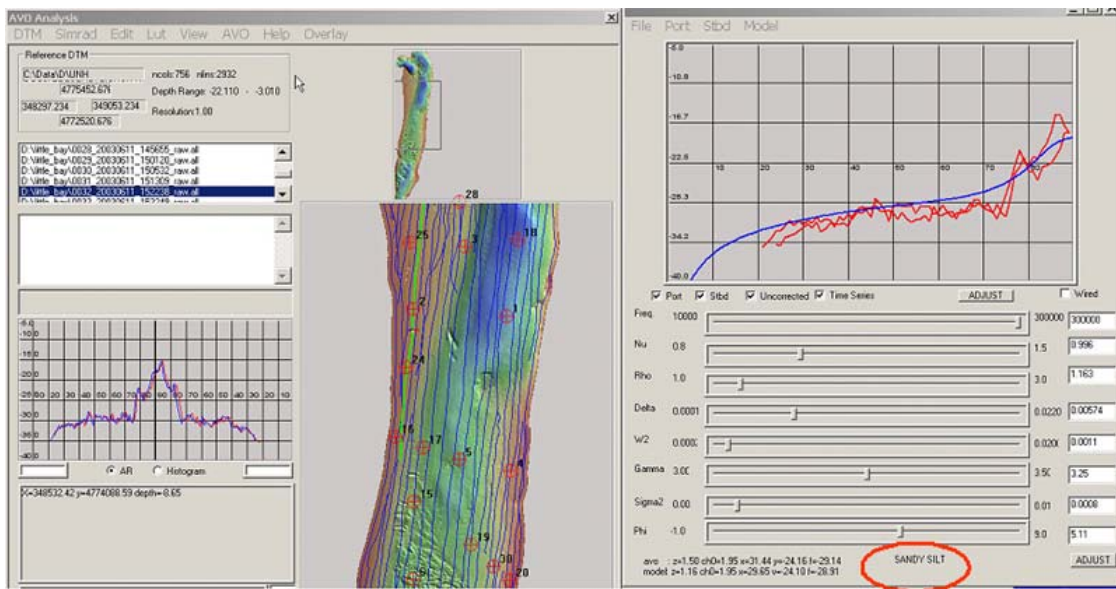

Figure 2. ARA tool with angular response curve and inverted solution for sediment type

Ground-truth comparisons:
While the ARA model offers a physics-based approach to direct prediction of sediment properties from acoustic backscatter data, all models must be tested and verified through the collection of ground-truth data. Building on the pioneering work of Ed Hamilton, Navy-sponsored researchers have, for more than 40 years, been collecting seafloor samples and making direct measurements of key geoacoustic properties. The resulting database of inter-property relationships has served as a key component of many seafloor characterization approaches as it allows the prediction (within certain constraints) of numerous seafloor properties from parameters that may be determined remotely (e.g. the prediction of grain size from a direct acoustic measurement of acoustic impedance). More recently, we have developed an instrument (*In-situ* Sound Speed, Attenuation and Porosity – ISSAP – Mayer et al., 2002) capable of making very reliable in situ measurements of geoacoustic properties (sound speed, attenuation, and resistivity from which porosity can be derived). The ISSAP has added greatly to the pool of direct property measurements as well as to our understanding of seafloor property inter-relationships (Kraft et al, 2002,. Kraft et al., 2006). As a critical step in developing our approach to the

remote identification of seafloor properties we will be using both direct seabed sampling (cores amd video imagery) as well as the ISSAP to of "ground-truth" and verify our characterization algorithms. Furthermore, this effort will add to the general database of geoacoustic properties inter-relations.

Small low-power multibeam sonar and AUV:
The seafloor characterization work that we have done to date has focused on high-end, surface-ship mounted multibeam sonars. In order to provide a seafloor characterization system in denied areas, we must strive to deliver this same capability on an autonomous vehicle that can operate covertly. Our efforts this year have thus also focused on the evaluation of a newly introduced, small-footprint, low-power multibeam sonar system (Imagenex Delta-T) and the integration of this system into an autonomous underwater vehicle (The University of Deleware's DOERRI vehicle – a Prizm Fetch 3.5 class AUV). Our approach was to calibrate and fully understand the capability of the Delta-T MBES to determine if it is feasible to apply the ARA technique to the data collected from it while at the same time evaluating the capabilities of the DOERRI AUV so as to evaluate its appropriateness as a platform for the remote deployment of the MBES.

WORK COMPLETED

Geocoder/ARA Modeling:
The Geocoder/ARA backscatter analysis package continues to evolve. Support has been added for a number of new sonar systems including Reson 7K series, Seabeam 2100 series, Simrad EA600 sidescan sonars, and the new Benthos C3D system and a graphical tool has been added to edit and interpret the selection of response curve parameter in the slope/intercept plane. Additionally, the ability to incorporate backscatter from multiple frequencies over the same piece of seafloor has been added to the ARA. Most importantly a fundamental constraint of the approach (the need to average over a swath-width in both the across-track and the along-track direction – which limits the spatial resolution) has been addressed through the development of a "thematic analysis" approach. The thematic analysis analyses examines the angular response of small areas on the seafloor and then segments the entire region into areas of common angular response (either manually or automatically). This approach may result in a high-resolution and more robust estimates of seafloor properties (see results section).

Ground Truth Studies:
Our initial plan was to focus our ground-truthing studies on the local waters of Portsmouth Harbor. Delays in the delivery of a winch to our new research vessel, however, prevented us from carrying our ground-truth work locally, so we refocused our effort on another area where a tremendous amount of ground-truth and sonar data already existed and is continuing to be collected. The area is the HARS (Historic Area Remediation Site) off the coast of New Jersey (Fig. 3) and the work, carried out in collaboration with SAIC who has been working in this area for many years, became the focus of the thesis work or Luis Soares Rosa.
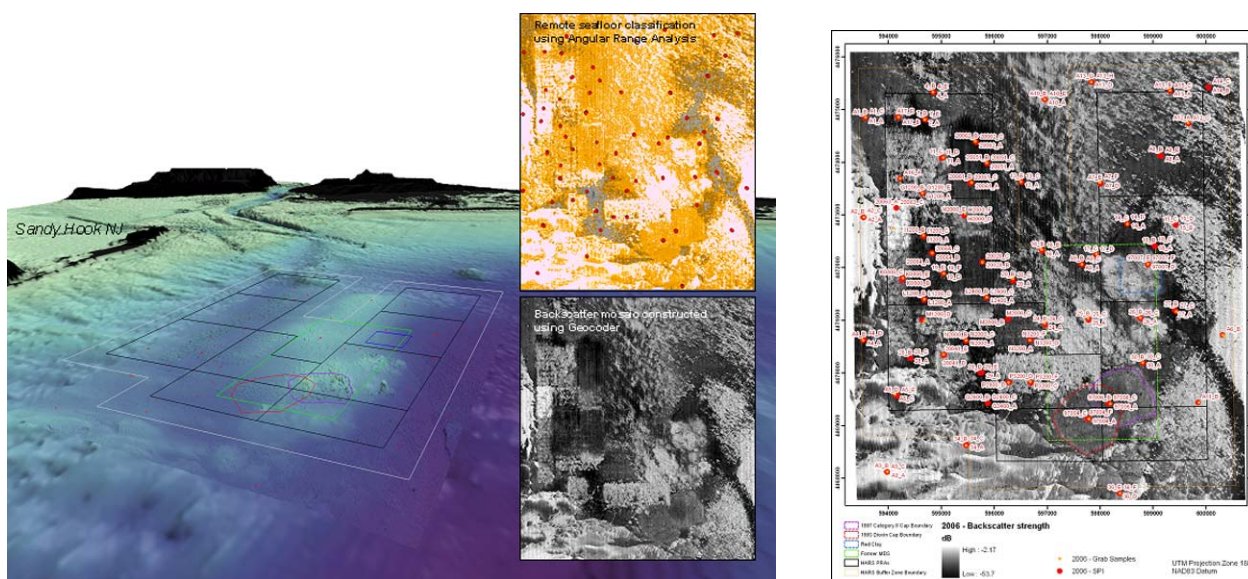
Figure 3. HARS field area (left) with backscatter mosaic and ARA grain size analysis. Sample locations superimposed on backscatter mosaic (right).

Building on the historical database of samples and sonar data, Soares Rosa participated in the collection and analysis of Reson 8101, 240 kHz MBES data, numerous grab-samples, and sediment profile images (Fig. 3). The backscatter data was processed using the ARA technique and then compared to the ground-truth. Results are discussed below.

Imagenex Delta-T MBES:
The Imagenex Delta-T is a new compact, low-power multibeam sonar that has been designed specifically for AUV deployment. The Delta-T forms 120, 3 degree beams over a swath width of 120 degrees. Calibration tests were conducted on the Imagenex Delta-T multibeam sonar at the UNH Acoustic Calibration Facility to verify the operational frequency, transmit and receive beam patterns, the transmit pulse width and the source level at a range of system settings. To determine the receive element spacing and phase offsets, Delta-T native 837 files were recorded while a calibrated pulse was transmitted by the E27 and received by the Delta-T in one degree increments while rotating the Delta-T from ±45°. A new LabView program was written to control the transmit timing of the Delta-T and E27 so that the receive characteristics of the Delta-T could be measured. Delta-T 837 files were also recorded for each setting of receive gain (1 dB steps from 0 to 20 dB) and display gain (20% increments from 0 to 100 %). All tests were repeated following repairs and upgrades to the Delta-T. MatLab scripts were created to read the 837 files and process the raw receive element data for phase difference as a function of rotation angle. In addition to calibration of the Delta-T, the ISSAP probes were also calibrated in preparation for their deployment.

DOERRI (Fetch3.5 Class) AUV Evaluations:
A close collaboration has been established between the UNH and UDel teams including many exchanges of equipment and personnel. The Delta-T has been fully integrated into the DOERRI (Fig. 4) and software developed to allow control of the Delta-T from the DOERRI control software.

Figure 4. DOERRI AUV with Delta-T MBES module (black module in center) undergoing trials

Beginning in October 2006 and ending in August of 2006 a series of AUV field campaigns and laboratory test tank operations were conducted in New Hampshire, Delaware, and the Black Sea to collect test data using the Delta-T and DOERRI.

RESULTS

ARA Model/Ground Truth Comparisons:
Comparisons of the ARA results with ground truth measured proved very encouraging. When the sediment sampled was both laterally and vertically homogeneous (within the uncertainty of the relative positioning of the sample and the acoustic data, the ARA used in the "normal" (averaging over a swath width) mode proved to be a very effective predictor of the mean grain size of the sediment (R2 = 0.90 – Fig. 6); when there was substantial lateral variability, the "theme" mode of the ARA proved to be a better approach. The "theme mode" starts with the segmentation of the backscatter mosaic in areas with similar tonal and textural patterns, called "themes". Each theme is expected to correspond to portions of the seafloor with similar geoacoustic and physical properties. The second step is the calculation of the average angular response for each theme, by considering all the acoustic samples from all the acquisition lines that fall within each theme. The final step which includes extraction of ARA-parameters, model inversion and prediction of seafloor properties, follows the same process as for the "normal mode". The difference in the ARA predicted mean grain size and the measured mean grain size is ± 0.4 phi at 1 sigma (Soares Rosa, 2007).
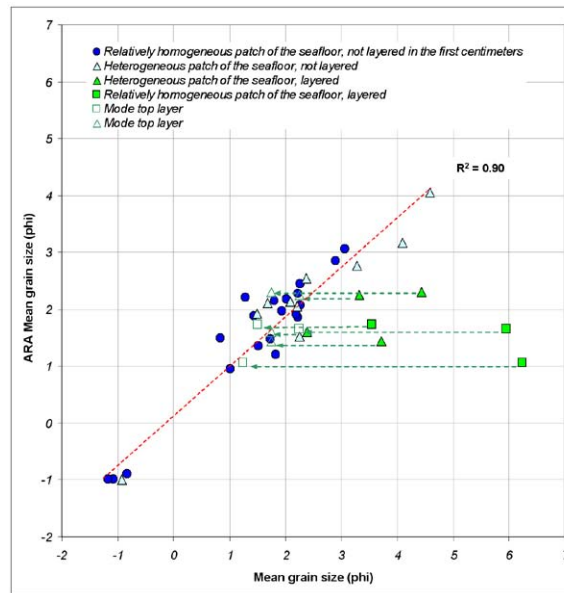
Figure 5. Results of comparison of predicted (by ARA) grain size with measured grain size at HARS.

Delta-T MBES Evaluations:
Initial tests verified the Delta-T operational frequency of 260 kHz. Using a NUWC USRD E27 reciprocal transducer as the receiver, the across-track transmit (Tx) beam pattern was measured. The Tx beam pattern was measured repeatedly to ensure the E27 was aligned correctly with the Delta-T Tx transducer and any pitch and roll offsets due to the mounting hardware were resolved. The 3 dB beam width was determined to be approximately 90° while a beam width of 120° corresponded to 6 dB. Delta-T Tx waveforms were recorded on the E27 to verify the Tx pulse width and source level at each range setting.   While the initial results of these calibrations were encouraging, we (and other investigators) have run into a road-block with the manufacturer of the Delta-T who refuses to provide further information about the operation of the sonar and has promised to encrypt any output from the sonar in subsequent upgrades. If the manufacturer continues on this path it will preclude our use of the system for quantitative backscatter analysis and we will seek another approach.

AUV Results:
Once the Delta-T MBES was integrated mechanically and electrically into the DOERRI AUV we moved into the software integration and field data collection phase of the project. Our software development effort allowed for direct ping to ping control of the unit with an ability to adjust range, gain, and beam size characteristics on-the-fly. Accessible software systems allowed for rapid integration of the Delta-T into the DOERRI framework and of DOERRI into visualization systems previously and continuously under development at CCOM (i.e. GEOZUI4D – Fig. 6).

In parallel with our software integration effort we embarked on an extensive field campaign for data collection. Field data collection was done on a somewhat ad hoc basis whenever personnel and/or ship time became available for operations. In total over 26 days of field operations and more than 60 individual missions (commanded surface or dive runs) were conducted in the following diverse coastal locations: Mendum's Pond, NH (Figure 6); Delaware Bay entrance; Great Bay, NH (Figure 7b); Pepper Creek, DE; and the Crimean Peninsula of the Black Sea. In the course of our field campaigns

we amassed more than 4.2 gB of raw Delta-T 837 data files that were used in the evaluation and software development effort and remain archived and available for MBES system evaluation. However, given the ad hoc nature of the field campaigns a full and sufficient suite of ground truthing data was not concomitantly collected thus a future task remains to collected AUV based MBES data in an area with high fidelity and high density ground truth data about seafloor properties. During its final mission in the Black Sea, the DOERRI suffered a catastrophic failure. The system was recovered but written off as a total loss. An insurance settlement has been agreed upon and a replacement system is being procured with a contract delivery date of 15 April.
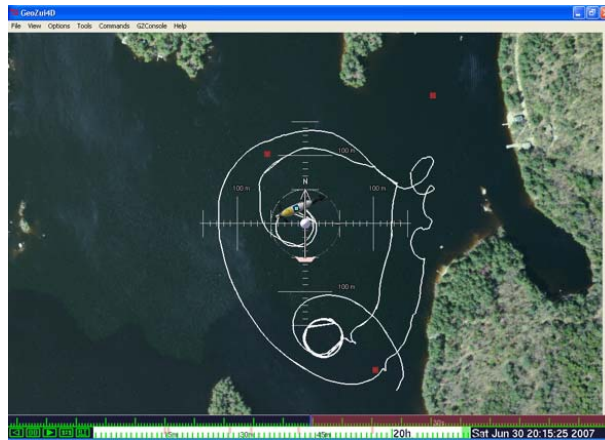

Figure 6. DOERRI AUV missions portrayed in real-time
in the GEOZUI4D visualization system.

IMPACT/APPLICATIONS

Results from validation of ARA approach imply that within limits it may offer a robust prediction of seafloor properties. If this continues to be proven true, the development of an AUV-deployed system will offer an approach for estimating seafloor physical, acoustic and geotechnical properties in denied areas at spatial and temporal scales appropriate for tactical applications.

TRANSITIONS

Geocoder/ARA have been transferrd and are now being implemented by numerous industrial partners including CARIS, IVS, Fugro, Kongsberg/Simrad, Reson, Triton, HYPACK, and Chesapeake Technologies as well as several NOAA labs. It is also in use by numerous university labs.

RELATED PROJECTS

Fluid-Mud Interaction MURI

Tidal Flats DRI

NOAA-OE Byzantium 2007 Geoarchaeology and seafloor mapping project

NOAA-OE Bonaire 2008 Remote habitat mapping in a tropical shelf setting

NOAA-SG Baymouth Circulation- Badiey, Wong, and Trembanis: 3 cruises aboard the R/V Sharp afforded at sea trials and testing of the AUV/multibeam system. The SG project benefited from the situational visualization system that was made available during the cruises

NSF-DE-EPSCoR- Pepper Creek: Trembanis, Targett, diToro: 4 field surveys at Pepper Creek DE afforded on the water testing of the AUV/multibeam system. The EPSCoR project benefited from the situational visualization system that was made available during the field work

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HONORS/AWARDS/PRIZES

Larry Mayer, University of New Hampshire, Faculty Research Excellence Award, University of New Hampshire

Larry Mayer, University of New Hampshire, Distinguished Achievement Award, Graduate School of Oceanography, University of Rhode Island.

Art Trembanis, University of Delaware, Excellence in Teaching Award. Department of Geological Sciences.

Art Trembanis, University of Delaware, CASEE Young Investigator Award. UK NURC, National Oceanography Centre Southampton UK.